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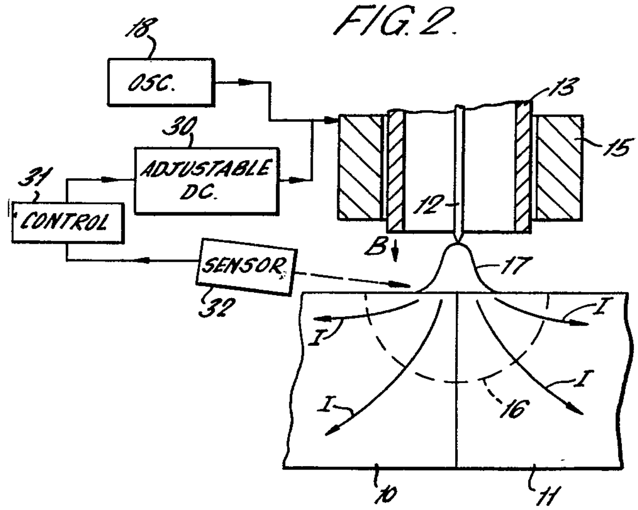
(54) Stirring an arc welding pool

(57) Good mixing of metals to be arc welded is achieved by magnetically stirring the weld pool using, for example, an electromagnetic field generated, by a solenoid 15.

Alternatively the magnetic field may be produced by a permanent magnet.

The metals to be welded may be different.

FIG. 2.



The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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FIG. 1.

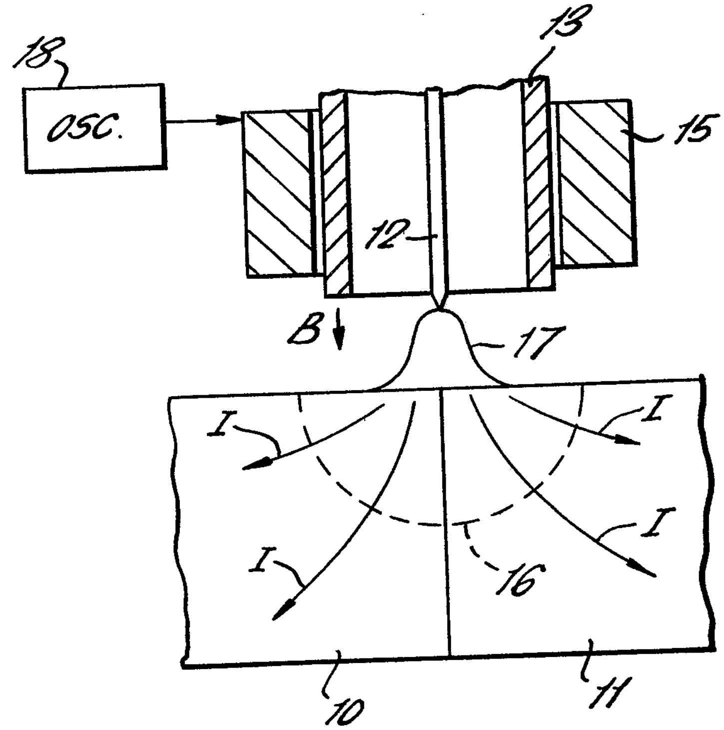
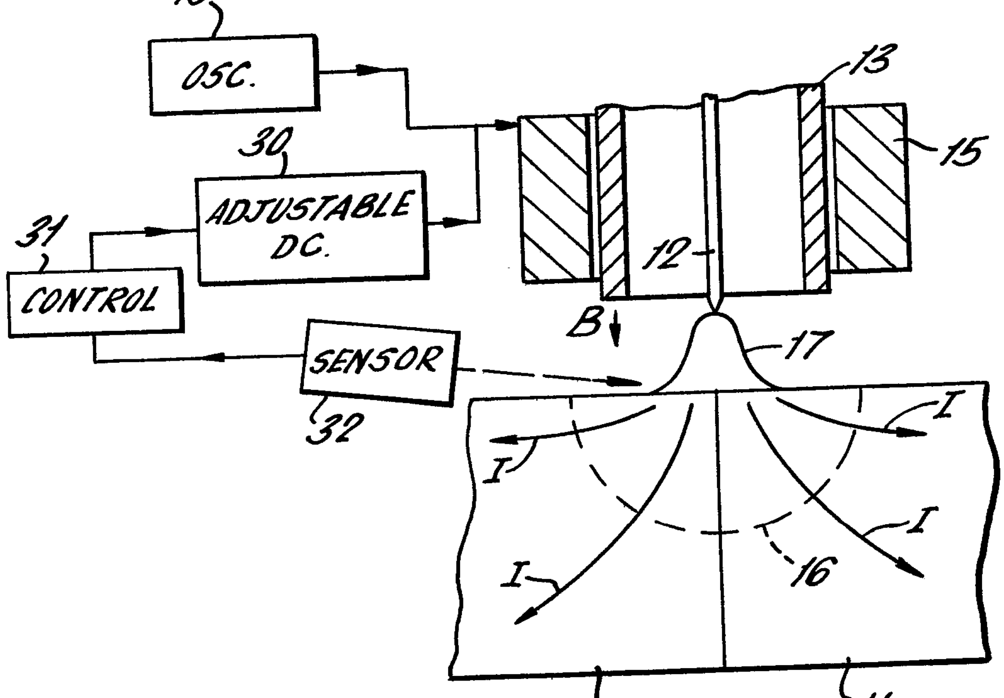


FIG. 2.



SPECIFICATION

Improvements in or relating to the butt welding of two elements

This invention relates to the butt welding of two elements of the same or of dissimilar metals.

In the design of many structures, the problem arises of joining components of dissimilar metal, for example different steels. Some freedom of choice in material composition is desirable, for example for maximum resistance to local environmental conditions, but if welding is to be employed, weld integrity has to be assured.

As an example a nuclear boiler might be constructed of three different steels, mild steel being used at the lower temperature end for economy and type 316 stainless steel at the higher temperature end with an intermediate portion constructed for example of a steel containing 9% chromium and 1% molybdenum. Using conventional TIG (tungsten inert gas) welding techniques, it is often found that the dissimilar metals are not completely blended in the weld pool and that anomalous slag islands are formed on the weld pool surface. These slag islands perturb the arc root during welding and, with it, the weld fusion zone. Occasionally internal defects, such as lack of side wall fusion or slag occlusion or cracking occur in such welds of dissimilar metals.

As will be explained hereinafter, the invention, in one of its aspects, however, is more generally applicable to the butt welding of two metal elements together, whether they are made of similar or dissimilar materials.

According to one aspect of this invention, in a method of welding dissimilar metals employing a welding process in which current passes through a liquid metal zone forming a weld pool, a magnetic field is generated having an axis substantially normal to the surface of the weld pool and coincident with the root of the arc to cause stirring of the metal in the weld pool about the root of the arc to form a mixed zone composed of the two materials.

Such magnetic stirring may be employed in welding processes in which a current passes through a liquid metal zone, for example in submerged arc or manual metal arc or MIG (metal inert gas) or TIG welding processes. It is readily possible, by a suitable choice of the magnetic field strength, to ensure full mixing of the metals in the weld pool. The rotational movement of the liquid metal tends to disperse any slag formation on the surface of the weld pool and helps to bring to the surface any occlusions trapped in the body of the liquid metal.

If the arc current is undirectional, the magnetic field may be a unidirectional field to give unidirectional stirring. A unidirectional magnetic field can be obtained using a permanent magnet or a solenoid. In some circumstances, e.g. in welding aluminium, an alternating current arc is preferred. The magnetic field in this case may be produced by a solenoid energised with an alternating supply synchronised with the arc current to give unidirectional stirring. Unidirectional rotation however gives rise to asymmetric heat flow in the weld pool with respect to the welding centre line as relative movement is effected between the welding head and the workpiece along the line of the weld. Hence, with a unidirectional field, the weld pool may be skewed with respect to the line of the weld. This depends however on the orientation of the workpiece and may, for example, with horizontal/vertical welding, compensate for the asymmetry due to gravity. In other cases, e.g. with downhand welding, correction may be desirable. This may be achieved by periodically reversing the direction of stirring as the weld progresses. Such reversal can be obtained by reversal of the magnetic field if the arc current is unidirectional. If the arc is an alternating current, the direction of stirring may be reversed by reversing the phase of the solenoid supply with respect to the arc current. If the period of reversal is too short, inertial forces in the pool will preclude any significant motion being induced. The frequency of reversal of the magnetic field however is not critical and it is readily possible to determine empirically a suitable frequency for the field reversal and/or a suitable d.c. bias. In practice any frequency over a wide range can commonly be used; typically a frequency of a few Hz may be employed. It will be appreciated that the magnitude of the stirring force will depend on the magnitude of the magnetic field and hence also affects the amount of motion induced in the pool. The applied magnetic field tends to increase the width to depth ratio of the weld pool because of the lateral spread of the heat. For this reason, it may be preferred to keep the duty cycle (the ratio of on to off periods) of the stirring to less than 50%.

Unidirectional stirring gives rise, as previously explained, to asymmetric heat flow in the pool and thus tends to skew the weld pool with respect to the line of the weld. The orientation of the workpiece has to be considered since, for example, gravity may also tend to give asymmetry to the weld pool position. As previously explained, asymmetry due to the magnetic field may be overcome by periodic reversal of the direction of stirring. The field is coaxial with the arc and hence rotates the arc without, however, directly altering its position. The fusion zone in the workpiece can be moved with respect to the centre line of the workpiece by altering a d.c. bias on an alternating or switched signal producing the magnetic field. This technique thus enables the weld pool position, considered in the transverse direction across the line of the weld, to be controlled with a non-contact method of control which operates directly on the heat dispersal without altering the position of the arc. This technique may be used for open-loop control of the position of the fusion zone or, with a suitable sensor or sensors, in a closed loop control system for automatic control.

Thus, according to another aspect of the invention, a method of welding using an arc between a welding head and a workpiece to produce a weld pool and in which relative movement is effected between the welding head and workpiece, a solenoid is provided for producing a magnetic field aligned with the arc to cause stirring of the weldpool and an adjustable direct current is passed through the solenoid to effect adjustment of the position of the weld pool

relative to the arc in a direction transverse to the direction of said relative movement.

The direct current may be superimposed on an alternating current or a current alternately switched to reverse its direction; the alternating current or switched current producing stirring of the weld pool. In the simplest arrangement, the direct current may be adjusted in magnitude to effect the control.

In a preferred arrangement, the position of the weld pool is sensed by a sensor which gives an output used for automatic control of the position of the weld pool.

The invention furthermore includes within its scope welding apparatus having a welding head for producing an arc between an electrode and a workpiece, means for effecting relative movement between the welding head and the workpiece and a solenoid around or adjacent the workpiece to produce a magnetic field aligned with the axis of the arc, together with means for feeding an adjustable or adjustably controlled direct current through the solenoid. The weld pool position may be sensed by a sensor e.g. using optical means to focus an image of the weld pool on a photo-diode array or using a scanning light beam, e.g. a laser beam, to determine the position of the weld pool, e.g. by measuring the reflectivity, and the output of such a sensor may be arranged to control the current through the solenoid.

In the following description, reference will be made to the accompanying drawings in which Figures 1 and 2 are each a diagrammatic illustration showing part of a welding head and adjacent workpiece comprising dissimilar metal elements to be welded together.

Referring to Figure 1 there is shown a workpiece comprising two elements 10, 11 to be welded together with a butt weld. These elements are of a dissimilar metal and it is required to form a weld along the line of abutment of the two elements and in which mixing of the two different materials has occurred along the length of the weld. In the embodiment illustrated the welding is shown as being effected by a TIG torch comprising a tungsten electrode 12 with a surrounding ceramic shield 13, a gas supply of argon or of argon with up to typically 10% hydrogen being injected to form a shielding gas around the electrode and arc. Around the head of the torch is a solenoid 15 which produces the magnetic field coaxial with the axis of the arc, the direction of this field being indicated by the arrow B. In the workpiece, there is a pool of molten metal indicated at 16. The current flow from the electrode through the arc shown at 17 spreads out in the workpiece as indicated by the arrows I. The interaction of this current with the magnetic field produces forces causing circulation of the molten metal around the axis of the arc.

The solenoid 15 is energised with a low frequency alternating current, for example a current which is periodically reversed at a frequency of a few Hz. Conveniently a sinusoidal current from a suitable power generator 18 is used for this purpose. The magnitude of the magnetic field is made such that this field is comparable with the self-magnetic field produced by the arc current, which might typically be of the order of 100 amperes. In a typical TIG torch, the magnetic field might be of the order of 0.01 T. Neither the magnitude of the field nor the rate of reversal is critical. If the field is not reversed, there is asymmetric heat flow in the pool and hence the weld pool would be skewed with respect to the line of the weld. The periodic reversal restores symmetry and the period of reversal and magnitude of the field are made such as to give suitable motion to the metal in the weld pool to achieve the required mixing. It will be appreciated that the amount of movement of the metal will depend on the time integral of the force applied and the period of rotation in one direction. It is readily possible empirically to determine the required magnetic field strength and frequency of reversal to obtain a symmetrical weld with adequate mixing of the metals from the two component parts.

Figure 2 illustrates another embodiment of the invention in which use is made of the asymmetric heat distribution produced by a direct current through the solenoid. In the following description of Figure 2, the same reference characters are used as in Figure 1 to indicate corresponding components and mention will be made only of the distinctive features.

An adjustable direct current source 30 is provided for feeding a direct current into the solenoid 15. This is shown in Figure 2 as being superimposed on the alternating current. The adjustable direct current is controlled by a control unit 31 responsive to the output of a sensor 32 which senses the position of the weld pool. In one example, the sensor 32 is a photo-diode array onto which is focussed an image of the front face of the weld pool in the neighbourhood of the arc. The output of the photo-diode array is a signal representative, in this case, of the transverse location of the weld pool with respect to the line of movement of the arc relative to the workpiece and the control system is arranged automatically to maintain the weld pool in the required location with respect to that line. Such a control arrangement could equally well be employed to maintain the required location of the weld by sensing radiation from the rear face. Other forms of sensor may be employed, e.g. a scanning light beam, more particularly a laser beam, with a sensor responsive for example to the reflected light.

CLAIMS

1. A method of welding dissimilar metals employing a welding process in which current passes through a liquid metal zone forming a weld pool wherein a magnetic field is generated having an axis substantially normal to the surface of the weld pool and coincident with the root of the arc to cause stirring of the metal in the weld pool about the root of the arc to form a mixed zone composed of the two materials.

2. A method as claimed in claim 1 and having a unidirectional current in the arc wherein the magnetic field is a unidirectional field.

3. A method as claimed in claim 2 wherein the magnetic field is produced by a permanent magnet.

4. A method as claimed in claim 1 and having a

unidirectional current in the arc wherein the magnetic field is produced by a solenoid fed with an alternating current whereby the direction of the magnetic field is periodically reversed.

5. A method as claimed in claim 1 and having a unidirectional current in the arc wherein the magnetic field is produced by a solenoid fed with a periodically reversed direct current whereby the direction of the magnetic field is periodically reversed.

6. A method as claimed in claim 1 and having an alternating current in the arc and wherein the magnetic field is produced by a solenoid energised with an alternating supply synchronised with the arc current.

7. A method as claimed in claim 6 wherein the phase relationship of the solenoid supply with respect to the arc current is periodically reversed to reverse the direction of stirring.

8. A method of welding using an arc between a welding head and a workpiece to produce a weld pool and in which relative movement is effected between the welding head and workpiece, wherein a solenoid is provided for producing a magnetic field aligned with the arc to cause stirring of the weld pool and wherein an adjustable direct current is passed through the solenoid to effect adjustment of the position of the weld pool relative to the arc in a direction transverse to the direction of said relative movement.

9. A method as claimed in claim 8 wherein the adjustable direct current is superimposed on a periodically reversed current.

10. A method as claimed in either claim 8 or claim 9 wherein the position of the weld pool is sensed by a sensor which gives an output used for automatic control of the position of the weld pool.

11. Welding apparatus having a welding head for producing an arc between an electrode and a workpiece, means for effecting relative movement between the welding head and the workpiece and a solenoid around or adjacent the workpiece to produce a magnetic field aligned with the axis of the arc, together with means for feeding an adjustable or adjustably controlled direct current through the solenoid.

12. Welding apparatus as claimed in claim 11 wherein means are provided for feeding a periodically reversed current through the solenoid in addition to the direct current.

13. Apparatus as claimed in either claim 11 or claim 12 wherein the weld pool position is sensed by a sensor and wherein the output of the sensor is arranged to control the direct current through the solenoid.

14. A method of welding two elements together substantially as hereinbefore described with reference to Figure 1 or Figure 2 of the accompanying drawings.

15. Welding apparatus substantially as hereinbefore described with reference to Figure 1 or Figure 2 of the accompanying drawings.

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